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Recent developments in the quality control of climatological data

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Summary

This paper describes, in brief, recent work within the Climatological Services Branch of the Meteorological Office in the use of multivariate statistical methods for the study of climatological data with particular reference to areal quality control. A fuller description of the investigation and methods used will be found in Spackman (1979, 1980).

Introduction

Climatological data archived by the Meteorological Office represent a resource of ever increasing value. Enquiries for which these data are used can relate to such major items as large construction projects, planning projects, and the assessment of alternative energy sources. At the other end of the financial scale, but still of considerable importance to the enquirer, are such matters as detailed weather on specific occasions and advice on the best areas for retirement or holidays. In order to use climatological data with confidence quality control is necessary, particularly because of the large number of enquiries which relate to legal cases for which certified or witness statements are required. Much information is also supplied for insurance claims which can, of course, be followed by litigation and, here also, statements of actual weather must be capable of withstanding legal scrutiny and questions.

Historical

Quality control has always been undertaken by the Meteorological Office for climatological data and, for many years, this was by 'hand and eye' methods making good use of the experience and expertise of individuals. Growth in the numbers of climatological stations and the turnover of staff made it necessary

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to introduce a degree of objectivity into quality control work and Bryant (1979a) described briefly the objective methods employed at that time. Basically, queries to climatological data are raised objectively but decisions upon what values should be archived following such queries are made subjectively. Computer archives contain the corrected data with flags set to show when a correction has been made while the 'paper archives' contain the original reports with amendments made in a contrasting coloured ink.

In this paper changes are described in the system used for areal quality control. Techniques for checking the internal consistency of reports from climatological stations, sequential checking, climatological extreme checks and so on remain more or less unchanged. Data entry is still by manual keying of data from manuscript returns for the 480 or so climatological stations which report once, or occasionally twice, per day. In WMO terminology these are known as Ordinary Climatological Stations. Official Meteorological Office stations and some auxiliary synoptic stations are now archived by accessing the synoptic data bank thus obviating the need for the keying of data from these stations. In total, there are about 140 of these stations of which about 60 report hourly. Most of these latter are Principal Climatological Stations in WMO terminology.

This paper concentrates on the quality control of temperature data, that is maximum temperatures, minimum temperatures, 0900 GMT temperatures, 0900 GMT wet-bulb temperatures and grass minimum temperatures. Quality control of anemograph data has been described by Bryant (1979b); soil temperatures, because of their conservative nature, are checked largely by means of sequential methods.

In 1975 a group was established within the Climatological Services Branch with the following general terms of reference:

(a) To study the factors which influence the several elements which make up the climate of a particular locality.

(b) To assess quantitatively, using appropriate statistical methods, the representativeness of an observing station and to specify the network of stations required to estimate the climate of a particular locality within specified limits in any part of the United Kingdom.

(c) To define a map of the United Kingdom showing climatological districts each having a relatively homogeneous or readily definable climate.

(d) To study statistical methods for the analysis of climatological data and for the presentation of information to users in the most effective way.

Factor analysis

In order to begin to study the variation of climate across the United Kingdom in an objective manner it was decided to concentrate on each climatological variable separately and to develop a technique which could be used reasonably easily for them all. Most of the initial investigational work was undertaken for daily minimum temperature because, from a climatological point of view, this is one of the more complex elements with values at individual stations being greatly influenced by local topography.

The decision to use multivariate statistical methods was made in order to gain familiarity in their use in this particular field. The relevant programs are now readily available in many statistical packages. Those used being the Biomedical Computer Programs (BMDP) described in Dixon (1975).

Factor analysis is a technique which aims at reproducing the correlation or covariance matrix of a set of variables measured on many cases from the knowledge of a small number of factors. Thus, a formidable volume of data may be reduced to manageable proportions. The factors identify modes of variation in the data and, it is hoped, may also point to the underlying physical causes. The particular

form of factor analysis used was Principal Component Analysis (PCA) followed by orthogonal rotation on the first few components. The aim of PCA is to attempt to assess the structure of variables within a particular set, independently of any relationship they may have to variables outside the set. PCA of a set of m original variables X_i produces m new variables called principal components denoted by c_i where $c_i = b_{i1} X_1 + b_{i2} X_2 + \ldots + b_{im} X_m$. The coefficients b_i are chosen subject to the conditions:

(a) Successive components have the largest possible variance.
(b) All pairs of components are uncorrelated.
(c) The sum of the squares of the coefficients involved in any one component equals unity (normalization).

The values of b_i are found by computing the eigenvectors of the covariance or correlation matrix, and the proportion of variance accounted for by each component is derived from the eigenvalues. It is possible to consider just a few of the components and perform a rotation on them by relaxing one or more of the above conditions to obtain what usually is termed a simpler structure. An orthogonal rotation which maximizes the variance of loadings within columns of the factor loading matrix is often used and referred to as a 'varimax' rotation. Within each factor this normally produces only large or small loadings—a structure that usually simplifies interpretation of the components. The final result may be expressed by

$$X_{ij} = a_{i1} f_{1j} + a_{i2} f_{2j} + \ldots + a_{ip} f_{pj} + r_{ij} \qquad (1)$$

where $f_{1j}, f_{2j}, \ldots f_{pj}$ are factor scores at each station j, $a_{i1}, a_{i2} \ldots a_{ip}$ are factor loadings for each factor, r_{ij} are error or residual terms accounting for the unexplained variance and X_{ij} are the original variables for day i for station j.

Data used

Daily values of minimum temperature, nominally measured at 0900 GMT, for 1973 to 1977 were used in the analysis. Most stations provided observations for each day and those with fewer than 99% of possible observations either had data missing for sequential periods, for reasons such as malfunctioning of instruments, or were stations which commenced or ceased operation within the period. Missing values were estimated by taking the mean of all values in the county for the day and adjusting this mean by the annual average difference between station value and county value. Estimates were only made for stations where there were at least 330 observations in the year. After the estimation of missing values there were about 670 stations each year with a complete set of daily values.

In order to reduce the effects of serial correlation and to provide a set of data for which the dependence between the variables had been minimized it was decided to use values at 3-day intervals. The actual values used in the analysis were anomalies of the temperature at each station with respect to the mean temperature over all stations on each day.

Results of the factor analysis

The decision on how many components were retained for the varimax rotation was based upon the variance explained by each component. Fig. 1 shows, for 1977, the variance accounted for by each component prior to rotation and it can be seen that the first few components account for most of the variances. Beyond component 20 the amount of variance accounted for decreases approximately as the logarithm of the variance. It was decided to rotate 15 components; this explained nearly 85% of the variance. The distribution of variance within each component is comparable each year—as shown by the values given in Table I.

In order to study the factors in detail use was made of a single-variable analysis package developed in the Central Forecasting Branch for the analysis of scalar variables. At each grid point on a 10-kilometre grid a weighted average of each factor was obtained in a similar fashion to the operational analysis of geopotential fields; isopleths of values at the grid points were then drawn using a microfilm plotter. It was noted that several of the factors were highly correlated with altitude. From a study of the patterns produced the following conclusions were drawn:

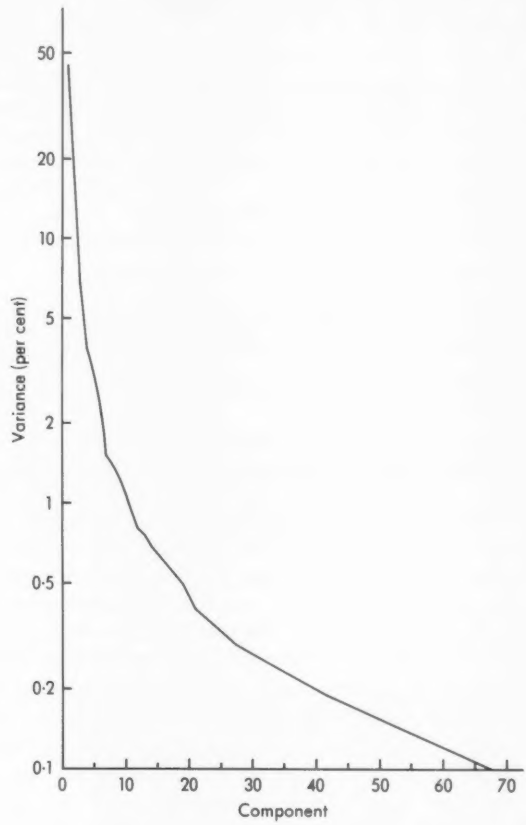

Figure 1. Variance explained by each component expressed as a percentage of the total variance for one year (1977).

Factor 1 represents an altitude variation superimposed upon a latitude variation—this is basically a 'latitude' factor.

Factor 2 shows a contrast, particularly over England and Wales, between inland and coastal regions. This is a contrast which is particularly marked on radiation nights under clear skies and anticyclonic conditions. Factor 2 may therefore be interpreted as a 'radiation' factor.

Table I. *Variance accounted for by first 15 components of Principal Component Analysis for daily minimum temperatures for 1973 to 1977. Values are given as* (° C)^2 *with cumulative percentages in brackets.*

Component	Year				
	1973	1974	1975	1976	1977
1	260.9(39.0)	247.9(45.6)	261.3(38.7)	234.6(38.5)	264.8(45.0)
2	132.2(58.8)	74.3(59.3)	111.3(55.2)	94.2(54.0)	87.6(59.8)
3	36.5(64.2)	28.6(64.6)	47.8(62.3)	35.1(59.8)	39.1(66.5)
4	31.3(68.9)	20.1(68.3)	29.8(66.7)	33.7(65.3)	23.1(70.4)
5	19.4(71.8)	15.4(71.1)	22.9(70.1)	22.6(69.0)	17.8(73.4)
6	15.2(74.1)	13.6(73.6)	20.4(73.2)	19.1(72.1)	13.2(75.7)
7	11.0(75.7)	10.1(75.4)	13.4(75.2)	16.2(74.8)	8.8(77.2)
8	9.1(77.1)	7.4(76.8)	10.5(76.7)	10.9(76.6)	8.5(78.6)
9	8.6(78.4)	6.8(78.1)	9.3(78.1)	8.4(78.0)	7.7(79.9)
10	7.3(79.5)	6.2(79.2)	8.2(79.3)	7.4(79.2)	6.0(81.0)
11	6.1(80.4)	5.7(80.2)	6.5(80.3)	6.2(80.2)	5.4(81.9)
12	5.5(81.2)	4.7(81.1)	6.3(81.2)	5.7(81.1)	4.9(82.7)
13	4.5(81.9)	4.2(81.9)	5.7(82.1)	5.4(82.0)	4.7(83.5)
14	4.4(82.5)	3.6(82.5)	5.4(82.9)	4.5(82.8)	4.0(84.2)
15	3.9(83.1)	3.5(83.2)	4.6(83.5)	4.1(83.4)	3.8(84.8)

Factor 3 is, broadly speaking, a contrast between the north of England, in particular the Irish Sea coast on the one hand and north Scotland and southern England on the other. This is apparently an 'Irish Sea' factor.

Factor 4 is an altitude variation superimposed on a west-south-west to east-north-east contrast—a 'longitude' factor.

Special features can be identified in many of the other factors, for example factor 6 shows the contrast across the Pennines, factor 7 is a coastal/inland contrast for north Scotland, while factor 9 is specific to East Anglia. Factor 10 shows a contrast between (i) the Scottish Lowlands and the coastal regions of the Moray Firth and Firth of Forth and (ii) the rest of the northern parts of the United Kingdom. Factor 12 is an east to west contrast over Scotland, and factors 13 and 15 seem to explain some of the individual responses of stations particularly over England and Wales.

There is no particular reason why any factor or factors should provide a physical explanation of the way in which minimum temperature varies from place to place. The factors are, simply, just one way of describing the variations of minimum temperature. Nevertheless, the relationships noted do support intuitive ideas and previous studies of the climate of the United Kingdom in which latitude, distance from coast, altitude and specific affects of topography have been found to be important. The comments made above regarding some of the factors were substantiated by evaluating the mean-sea-level pressure pattern for days when the various factors had high loadings - that is high values of the 'a' terms in equation (1). Factor 1 had high loadings with westerly flows, typical of average conditions, while factor 2 had high loadings under anticyclonic conditions. Factor 3 was important with a strongish north-westerly airflow and factor 4 with northerlies or southerlies. The relative importance of the other factors depended upon the position of the anticyclone or ridge conditions affecting particular parts of the United Kingdom.

Application of the factor analysis to quality control

The distribution of the residuals from equation (1) may be studied both with respect to day and to station in order to determine how well the factor model (equation (1)) fits the observed data on given

days or at particular stations. The residuals include error contributions from at least the following sources:

The inadequacy of the factor model in representing the peculiarity of a station site or the temperature variation on a given day.
Instrumental errors.
Observer errors.
Data processing errors.

Since the model accounts for a large proportion of the variance of the data it is worthwhile studying the residuals to identify stations with large values. Factors were obtained for 1973 to 1977 for both minimum and maximum temperatures and then data from all days of 1974 were used in a regression of minimum temperatures and maximum temperatures against these factors using the BMDP6M multivariate linear regression program. In order to use as many stations as possible the estimated values of missing data were used in the regression, but residuals from these values were not used in compiling statistics for each station. The standard deviation of the residuals ranged from 0.5 °C to 1.9 °C with a mean over all 627 stations of 0.97 °C for minimum temperatures. For maximum temperatures the standard deviation of the residuals ranged from 0.4 °C to 1.6 °C with a mean value of 0.79 °C over 598 stations.

A preliminary investigation of the general distribution of the standard deviations of residuals suggests that:

Residuals in the north of the United Kingdom tend to be larger than the south (this may, of course, merely reflect the differences in station density).

Known frost hollows usually have large residuals (greater than 1.1 °C).

Meteorological Office stations tend to have small residuals.

Stations with records over a long period tend also to have small residuals.

Values of the mean residual are generally small (i.e. less than 0.3 °C) although larger values have been found at some stations with incomplete records over the 5 years, and for some relatively isolated places such as the Isles of Scilly and stations in Orkney and Shetland.

Some stations which habitually have large residuals provide very severe problems during the quality control process. In some cases the reason is, simply, that the amount of missing data has rendered the derivation of the factors difficult. In other cases it may be that the station is unrepresentative; urban roof sites, such as London Weather Centre and Cheltenham, and frost hollows typically have large residuals.

By means of objective analysis of patterns of individual factors stations can be detected that do not fit the general pattern in one factor or another. These stations can be expected to be unrepresentative under the conditions when the factor or factors are important. Large values of residuals on a daily basis might indicate poor observing practices.

In order to detect suspect data on a day-to-day basis the residuals are studied after fitting the factors to the appropriate data by linear regression. The residuals, r_{ij} of equation (1), are given by

$$r_{ij} = (\text{observed value})_{ij} - (\text{estimated value})_{ij}$$

and an observation is defined as suspect if

$$S = \left| \frac{r_{ij} - \bar{r}_{ij}}{\sigma(r_{ij})} \right| \geqslant 3.25$$

where S is the 'standardized deviation', $\bar{r}_{ij}$ is the mean residual and $\sigma(r_{ij})$ is the standard deviation of the

residuals. For this test a mean and standard deviation are computed for the climatological area of the United Kingdom where the station lies. These areas consist of

Orkney, Shetland and Caithness
Isle of Man
Channel Islands
The 10 climatological districts (excluding stations in the above areas) shown in Fig. 2.

Appropriate sets of factors have been obtained for maximum temperatures, minimum temperatures, 0900 GMT dry-bulb temperatures, 0900 GMT wet-bulb temperatures, grass minimum temperatures and sunshine. Using the value of the standarized deviation as an indicator of suspect data the following observations can be made:

Where the standardized deviation is less than 3.5 then data are *usually* acceptable.

Where the standardized deviation is greater than 4.5 the observations will *usually* be in error.

Most unacceptable observations are detected by taking the limits of the standardized deviation at 3.25 although up to 50% of the suspect data may, in fact, be subsequently deemed acceptable.

It should not be assumed that data are necessarily wrong (or right) simply by use of the standardized deviation. Definitive identification of data which are erroneous, and only those data which are erroneous, is impossible.

The technique seems to work fairly well for temperatures but rather less well for sunshine; for sunshine it seems that small-scale variations are sometimes poorly fitted by the model resulting in several nearby stations with similar values all being queried. A 'hand and eye' technique involving the visual scrutiny of a computer-plotted chart of daily values is used in conjunction with the objective method.

Problems in fitting data (for all parameters) were greater in some districts than in others. For example, difficulties were encountered in coastal parts of East Anglia, outlying islands, and sparse data areas in mountainous terrain.

In certain extreme conditions, such as during December 1981 and January 1982, some correct data resulted in standardized deviations which, in normal circumstances, would have indicated a high probability that the data were incorrect.

Presentation of information on suspect data

An example of the output from the computer to the quality control staff is shown in Fig. 3. Suspect values are shown with a $\neq$ sign and are plotted with nearby values in their approximate relative geographical positions. All the data are also tabulated with their DCNN (the climatological station number—District, County, NN), first four characters of station name, and altitude (metres). For the suspect observation the printout contains the following:

DCNN
First eight characters in the name
Date (left blank if for a monthly mean)
Suspect element
Observed value
Residual
Probable reason for error
Estimated value
Standardized deviation.

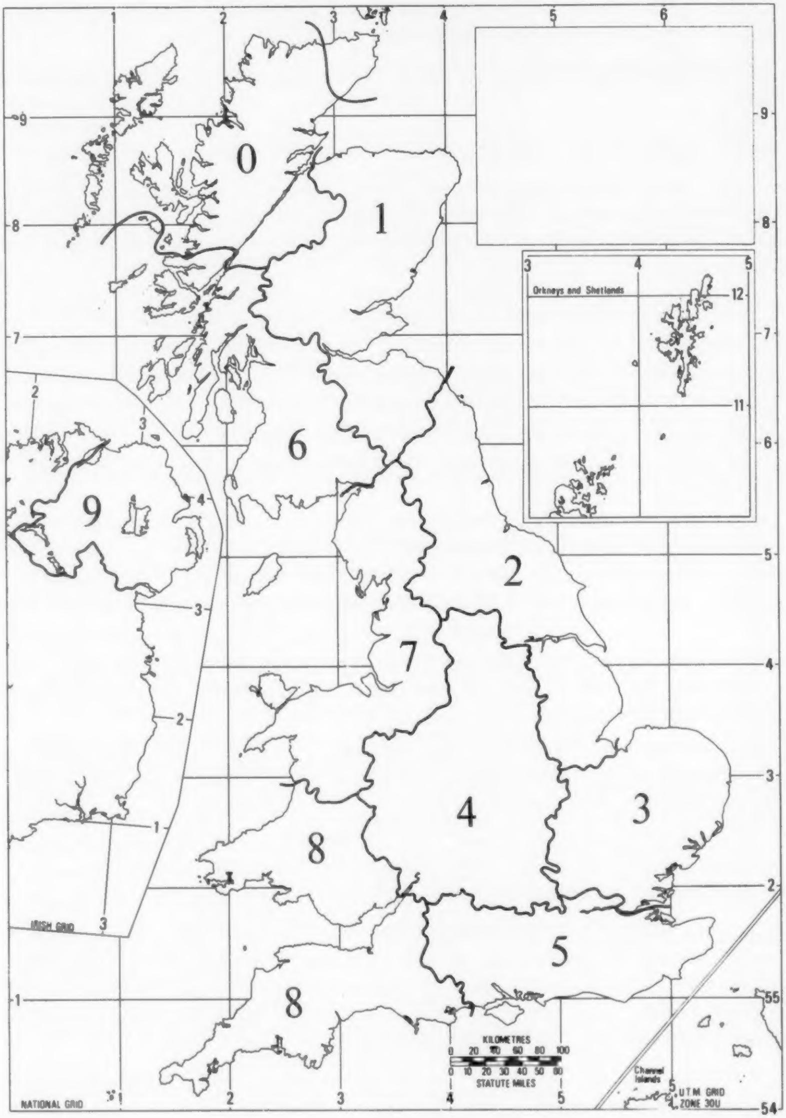

Figure 2. Areas for which means and standard deviations of residuals were computed.

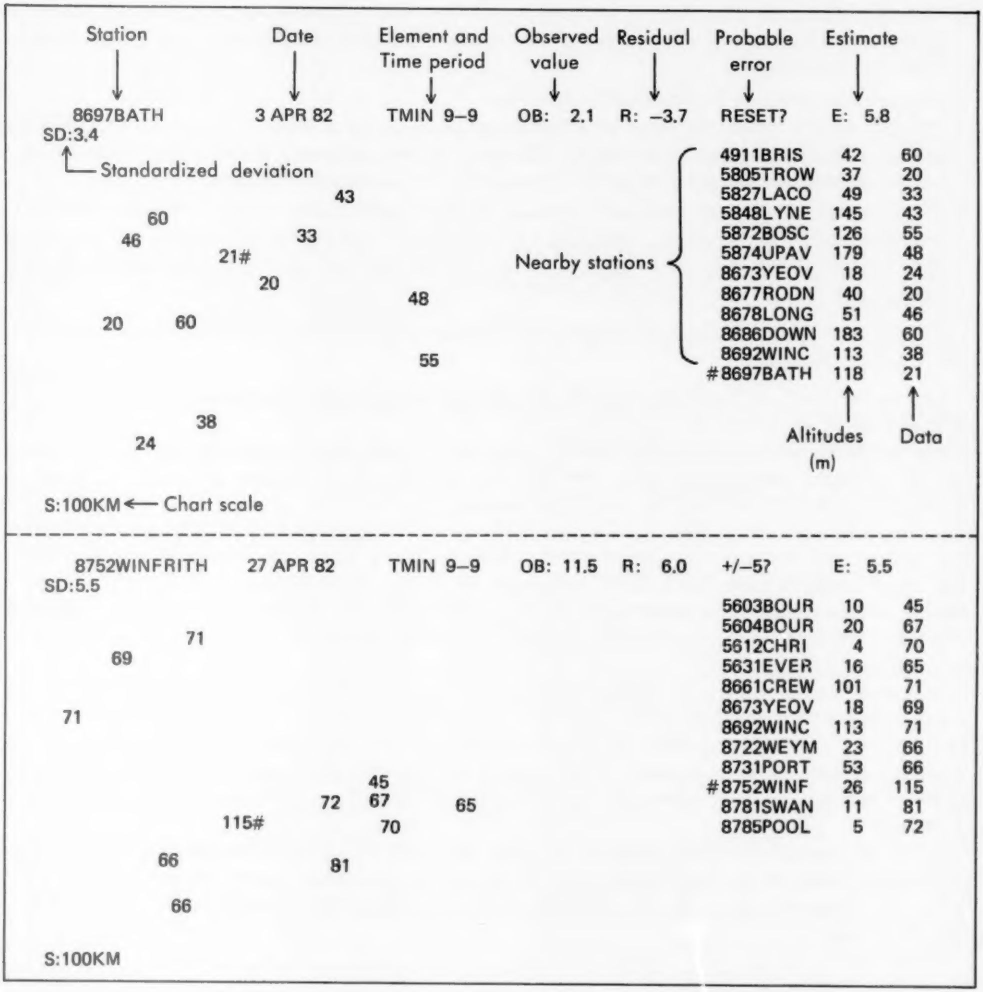

Figure 3. Examples of error printout for Bath (DCNN 8697) for 3 April 1982 and Winfrith (8752) for 27 April 1982. Standardized deviations of 3.4 and 5.5 indicate that observed values are 3.4 and 5.5 standard deviations from the estimate. The former is clearly a doubtful report and the latter almost certainly incorrect. Chart width normally corresponds to 100 km but can vary in areas where data are sparse.

ESTIMATE on the printout for the suspect value is obtained using the factor for the station in question and the factor loadings appropriate to the particular element and day. In other words it is an objective 'best guess'.

Reasons for error can be suggested as follows:

INDEX when a suspected value of a minimum temperature is about 7 °C below the computer estimate. This corresponds to the length of the index within the alcohol of the thermometer and it is a fairly common mistake for an observer to read the wrong end of the index.

SIGN when an apparently erroneous reading would be corrected by a change of sign.

RESET when a suspected value of maximum or minimum temperature is within 0.5 °C of the value read on the previous day. The implication is that the observer may have forgotten to reset the instrument.

+/−5 or +/−10 when a suspected temperature could be rectified by the addition or subtraction of 5 °C or 10 °C respectively.

The two examples in Fig. 3 show sample printout for minimum temperature at Bath on 3 April and Winfrith on 27 April 1982.

For the Bath report, inspection of nearby observations shows that Trowbridge (DCNN 5805) had a similar minimum temperature which was not queried. Bath is at a height of 118 m compared to Boscombe Down (DCNN 5872) at 126 m and Lyneham (DCNN 5848) at 145 m. It might be that on a night with radiation cooling the lower-level stations would be colder than those higher up and that Bath is indeed in error. However, inspection of hourly observations at Boscombe Down and Lyneham shows that cloud amounts were very variable that night. Boscombe Down reports show a decrease from $\frac{7}{8}$ stratus to $\frac{2}{8}$ between 0300 and 0500 GMT while Lyneham had $\frac{7}{8}$ throughout. On balance it was decided that while the Bath report was suspect there was not enough evidence for us to be sufficiently sure to propose an alternative value.

The report for Winfrith on 27 April is rather more clear-cut in that inspection of nearby observations confirms that 11.5 °C was anomalous and that a 5 °C error was probably made by the observer. A value of 6.5 °C was taken by the quality control staff as being the most likely value and this appears both in the computer archive and as an amendment to the manuscript return. Although still 1 °C different from the objective estimate, it is well within the expected range of possible values for the station on the night in question.

These two examples quoted clearly demonstrate that, even with a fairly sophisticated technique for detecting possible errors, the decision to accept or reject an observation must still be subjective. Even when it is accepted that a report is incorrect the assessment of the possible correct value is still a subjective one.

Further uses of factor analysis

One of the original aims of the investigation team which undertook this work was the definition of climatologically homogeneous areas. This work will be discussed in a future paper together with the use of factor analysis to determine climatological station network density requirements. Another application of factor analysis in studying climatological data is its use in indicating inhomogeneities in station records. In a test (Done 1980) the factor analysis technique was applied to monthly minimum temperatures for 125 climatological stations. Studies of the series of residuals showed some striking discontinuities which could, on many occasions, be correlated with changes of site, change of site characteristics or changes of instrument. It might be possible to use the same techniques to detect the

effects of changing land use. For example, a gradual rather than a sudden change in the character of the residual might indicate urban development near the observing station or an increase in shelter due to tree growth.

Conclusions

The use of factor analysis has been shown to be a powerful tool in the handling of large amounts of climatological data and the first application of the work has been to improve objectivity in the detection of possible errors in climatological data. In common with all quality control techniques the final decision as to what data are correct or incorrect must be a subjective one as must be the estimates of the likely correct values. The technique also has potential in evaluating the homogeneity or otherwise of long-term climatological records and, as such, is of value in selecting those stations which can be used for determining secular changes in climate.

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Winds estimated by the Voluntary Observing Fleet compared with instrumental measurements at fixed positions

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Summary

Measured wind speeds at fourteen offshore locations are compared with visual estimates made by the deck officers of merchant ships adjacent to the sites. The methods of measurement and estimation of the speeds are discussed together with their climatological reliability. Extreme values derived from the distributions of estimated wind speeds are compared to determine whether extreme values from visual estimates can be used with confidence when reliable wind speeds from instruments are not available.

1. Introduction

Observations of wind conditions over the ocean and seas come from two main sources, fixed position observing stations and merchant shipping.

Observers located at fixed position observing stations, for example Ocean Weather Stations (OWS) and light-vessels (LV), make wind measurements using anemometers, whilst the deck officers of merchant ships, which form the Voluntary Observing Fleet (VOF), estimate the wind speed from the state of sea at regular intervals during a voyage. Consequently, the fixed stations produce a set of regular observations for each position whereas the merchant ships provide a set of observations which are randomly distributed, along trade routes, in space and time.

Since there are few fixed measuring stations, and these are widely distributed, any analyses of winds over the oceans must depend largely upon observations from the VOF.

Measured observations have usually been considered more accurate than the visual estimates, and results derived from regular data at a fixed location rather better than those from estimates. Several studies have been made that attempt to relate these two types of observation and determine the relative accuracy of the VOF data, for examples see Quayle (1980) or Kaufeld (1981).

The purpose of this study was to look more closely at several different types of measured observation and at the VOF data in surrounding areas to establish, in general terms, the confidence that can be placed in the VOF data when no suitable measured data are available.

For the VOF estimates 18 years of data were available for this project, 1961–1978 inclusive. Periods covered by the measured data are shown in Table I. Where possible the same period of VOF data was used, for example OWS 'I' and 'J' and their corresponding VOF data covered 1962–1975, OWS 'M' 1962–1978 and the LV 1961–1978. For the other stations where only a short period of measured data was available it was decided to use all the available VOF estimates because using only those from the corresponding periods reduced the number of estimates considerably. For example, for Brent and DB 1 only one year of measurements was available for direct comparison with VOF estimates.

2. Estimated wind data

Wind speeds are estimated by the deck officers of merchant ships of many nationalities using essentially the same method. The observer estimates wind speed from the state of sea or sometimes, particularly at night, from the way the ship is handling. The Beaufort scale of wind force is used which is related to standard descriptions of state of sea. Each Beaufort force has speed limits, in knots (see

Appendix Table IA), assigned to it according to the scale adopted by the World Meteorological Organization in 1946. The observer then estimates, within those limits, a wind speed to the nearest knot.

Because of the use of these discrete groups the wind speed values recorded tend to cluster around the middle value of each Beaufort force range and, consequently, the data can only really be used in the Beaufort force classes. The scale used by the VOF is now considered incorrect and alternative limits have been devised for each scale number (see Appendix Table IA). This scale is commonly called the 'scientific' Beaufort scale by certain Branches of the Meteorological Office and should correct the speeds in those classes previously overestimated.

The averaging time or representative time for these observations is not really known but in this study it has been taken as equivalent to an hour owing to the relatively slow response of the sea to changes in wind speed. These estimated winds may be taken as hourly mean values of wind speed that are observed every six hours by the majority of VOF ships.

The data used were derived from ships' logbooks and should be complete. This was necessary because many ships do not transmit radio messages at night and so data from telecommunication sources are usually incomplete.

3. Instrumental data sources

A set of 14 stations was used, comprising four OWS, four LV, three stations manned by ships sponsored by the United Kingdom Offshore Operators Association (UKOOA), one island station, one oil rig and one data buoy. Locations are as shown in Fig. 1.

All these stations were equipped with anemometers, but observing practice varied from site to site. The methods used are presented in more detail below and a list of these stations with dates and total number of observations is given in Table I together with the corresponding dates and number of observations for VOF data.

(a) *Measured wind observations from ocean weather ships*

Ocean weather ships carry at least one anemometer in a well-exposed position. British weather ships carry two anemometers on a yard-arm, one on each side of the main mast, at a height of 20 m above sea level with dials on the bridge registering instantaneous wind speeds.

Table I. *Availability of measured wind data and periods for which estimated data were used in the analysis*

Station	Measured wind speeds Period	No. of observations	Estimated wind speeds Period	No. of observations
OWS 'I'	1962–75	113 072	1962–75	2 355
OWS 'J'	1962–75	112 317	1962–75	3 356
OWS 'L'	1975–79	28 957	1962–78	2 975
OWS 'M'	1962–78	126 335	1961–78	666
Seven Stones LV	1961–78	13 100	1961–78	12 410
Shambles LV	1961–78	9 988	1961–78	12 797
Mersey Bar LV	1961–78	8 192	1961–78	1 608
Varne LV	1961–78	46 194	1961–78	9 932
Stevenson (10 minute)	1973–76	2 005	1961–78	5 702
FitzRoy	1973–76	2 379	1961–78	3 088
Boyle	1974–77	3 643	1961–78	6 315
Stevenson (hourly)	1973–76	21 010	1961–78	5 702
DB 1	1978–79	5 888	1961–78	13 338
Brent B	1978–79	4 950	1961–78	9 178
South Uist	1961–78	29 266	1961–78	1 743

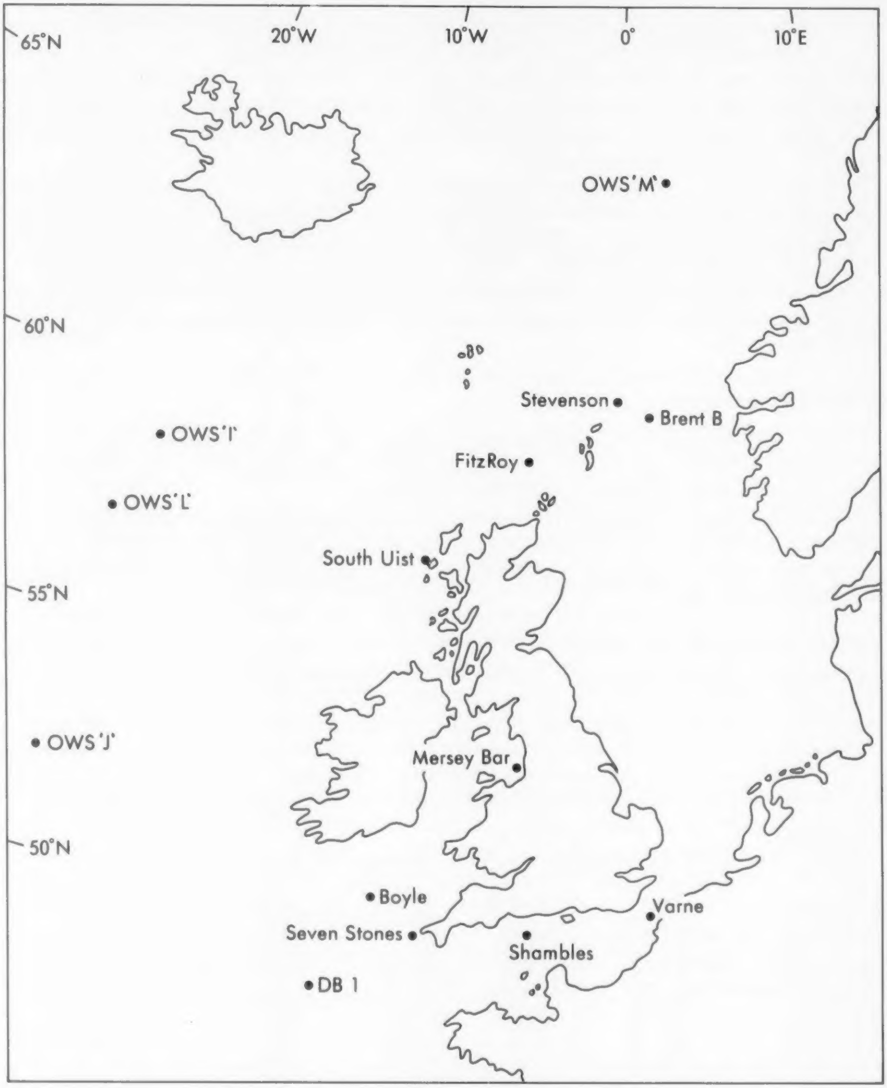

Figure 1. Positions of fixed stations used in the analysis.

The observer is instructed to take an average, by eye, of the dial readings over a period of 10–15 seconds at the time of observation. However, the precise method of making the observations is not clear. The *Marine observer's handbook*, which refers to British weather ships, makes the statement that 'even here estimates are made regularly of wind force and direction from the appearance of the sea as a check on the instruments'. Informal discussion with the weather ship observers suggests that the visual element may make a large contribution to the observation in some cases. Consequently, how many of the observations are averages over 10–15 seconds and how many are instrument assisted estimates with longer effective averaging times is unknown.

There are also uncertainties regarding the siting of the anemometers on ships of different nationalities and in the non-linear response of anemometers in wind speeds of less than 10 knots; in practice, Meteorological Office anemometers require a gust of approximately 2–4 knots to overcome instrument inertia before they begin to register wind speeds. The wind speeds are not corrected for the ship's pitch and roll, and also it is not known whether or not the ship was steaming when the observation was made: this can make a considerable difference to the pitch and roll of the ship, which in turn affects the wind speed recorded by the anemometer because the ship's motion is amplified by the height of the instrument above sea level.

(b) *Measured wind speeds from light-vessels*

Observers on LV are not professional meteorologists but are instructed on how to use hand-held anemometers to make the observation from a well-exposed part of the ship, and to take an average reading, by eye, of the wind speed over a 10-minute period.

It is difficult to achieve reasonable accuracy with a hand-held anemometer and the actual exposure of the anemometer is unknown, as is the actual length of time over which the wind speed is averaged. It is likely that the observer would find some difficulty in making an accurate estimate of the 10-minute mean speed and, therefore, that data from the LV are more representative of 1-minute mean wind speeds.

(c) *Measured wind speeds from UKOOA sponsored ships*

The data for the three UKOOA stations were taken from the meteorological logbooks. For Stevenson there is also a data set of quality controlled hourly mean wind speeds.

The data from the meteorological logbooks consist of measured values, but the source of measurement and averaging time is uncertain. It is likely that most of the data are from readings of anemometer dials, as on the OWS, but since chart recorders were available some readings may have been taken from these.

Unfortunately, the data sets cover short periods, about 3 years each, and have many gaps when no observations were made.

(d) *Other stations*

South Uist. The data for this position were taken from Benbecula, a land station equipped with an anemograph to record wind speeds. The data were provided by a manual analysis of the average wind speed over a 10-minute observing period in each hour. These data were included because wave data from a buoy moored off South Uist were to be used in a wave climate synthesis project currently in progress as a joint National Maritime Institute/Meteorological Office venture.

DB 1. DB 1 is a data buoy recording meteorological and wave data automatically. It has two anemometers, one mounted at 8.7 m above sea level and the other at 6 m above sea level. These provide instrumentally calculated 10-minute mean wind speeds every hour. This location should provide better 10-minute mean wind speeds than any other site because there is no doubt about averaging time or

exposure. Unfortunately, the record is so short that it is of little use in the estimation of extreme conditions over long return periods.

Brent B. (Oil rig owned by Shell) The anemometer on this rig is mounted on top of the drilling derrick at a height of 108 m above sea level in the best position available. The observations were made every three hours, readings being taken from a digital display and entered in the meteorological logbook from which the data set used here was compiled. These winds, therefore, must be considered 'spot winds' or 3-second gusts.

4. Reliability of measured data for climatological purposes

Reliability of data is a difficult quality to quantify because the properties that define it vary with the purpose for which the data are required. For example, data sources that are considered useful for synoptic purposes may not be acceptable for climatological investigations.

It is particularly important in climatology to be aware of the limitations of the data. Thus, it is necessary to be aware not only of the accuracy of each individual measurement, but also of the long term consistency of the method of measurement so that there are no discontinuities in the data which could affect any result derived from them. Such discontinuities can be due to changes in instrument type and method of observation, or changes in coding practice.

The prime requirement for climatological data is that they should cover as long a period as possible; three years of data is not really long enough for a data set to be considered representative of climatological conditions, but, often, the quality of the data themselves can be taken into account to increase confidence in the climatological reliability of the data set. This was the case with the data set of quality-controlled hourly mean wind speeds from the Stevenson site. The hourly means were derived from continuous recordings of wind speed from digital or analogue recorders and were fairly complete, 80% of the possible total number of observations being present. This compares favourably with an average of 75% for the OWS 'I' and 'J', although these data sets cover a period of 17 years.

The LV data sets cover a period of 18 years but, as mentioned above, the climatological reliability of each individual measurement is in question. The LV provide very useful observations on the synoptic scale since they can be considered in the light of the current situation. However, the accumulation of the doubtful measurements produces data sets of questionable climatological reliability.

It is unfortunate that there are only 18 months of data available from DB 1. In time these data should prove to be useful for climatological purposes, although the record will still be short. The method of measurement is known exactly and the only variable is the calibration of the instrument; this can be checked and the data adjusted accordingly.

5. Analysis of data

The descriptions of observing methods and other factors given above indicate quite clearly the difficulties involved in comparing measured and estimated values of wind speed. It has to be assumed that deck officers on ships of the VOF estimate winds in a similar fashion and this is supported by the similarity in the distributions produced for each site (Fig. 2). However, the measured distributions are all very different in shape. This is not only because of the different geographical locations but also the differences in anemometer height, the method of determining wind speed and the different averaging times used. Ideally, corrections would be applied to produce a consistent set of data, but this is not practicable owing to the uncertainty surrounding the observing practice.

Because of these inconsistencies it was not possible to make any direct comparisons between all the wind speed distributions. It was necessary to decide which of the measured distributions should be

considered reliable and to compare these with the corresponding estimated distributions. The data were required to cover a long period with few gaps, and with a known method of observation that was thought to be used consistently to make corrections possible.

Within these constraints the OWS were considered 'reliable' although with some reservations concerning the short period for OWS 'L'. The hourly data set from the Stevenson station was also considered 'reliable' since the data had been studied and quality controlled.

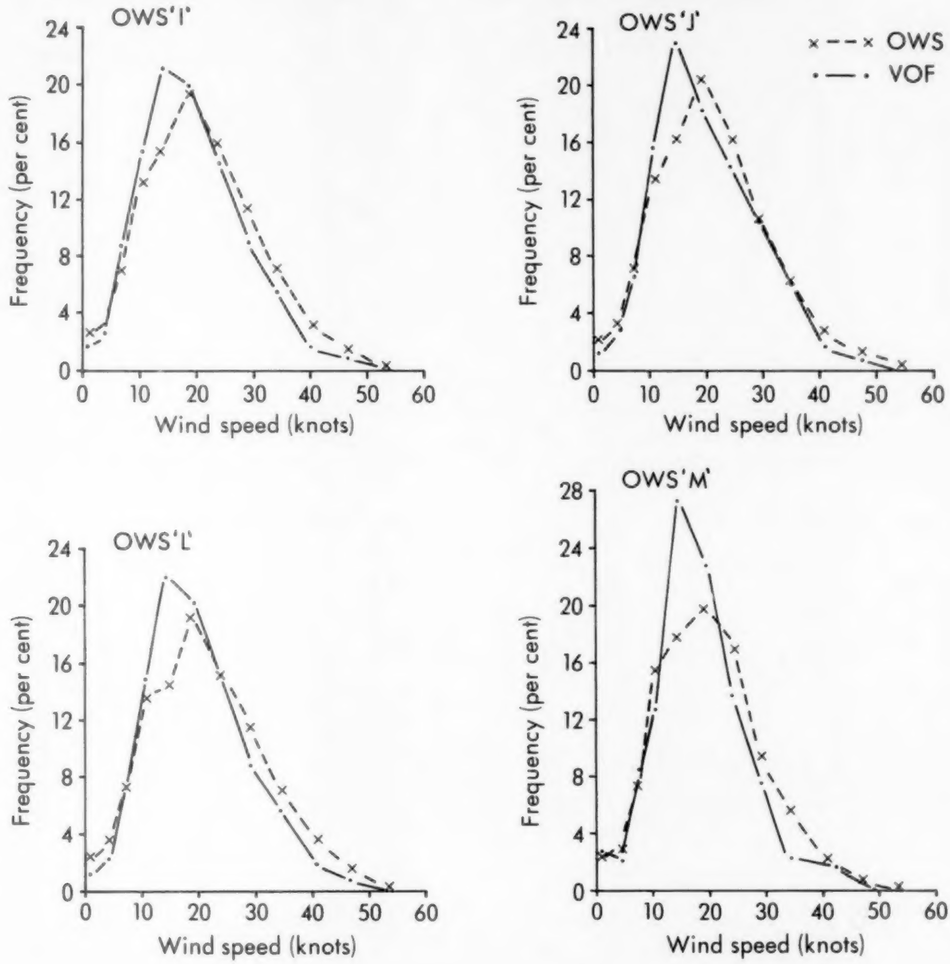

Figure 2(a). Wind-speed frequency distributions for OWS compared with those for co-located VOF ships within 2° × 2° squares centred on the OWS.

(a) *Simultaneous data and calibration of estimates*

For each site the instrumental wind speeds were compared with VOF estimated wind speeds made at the same time. These estimates were taken from 2° × 2° 'square' area around the instrumental source. Comparisons were not made when the wind directions differed by more than 45° unless one of the winds was a calm.

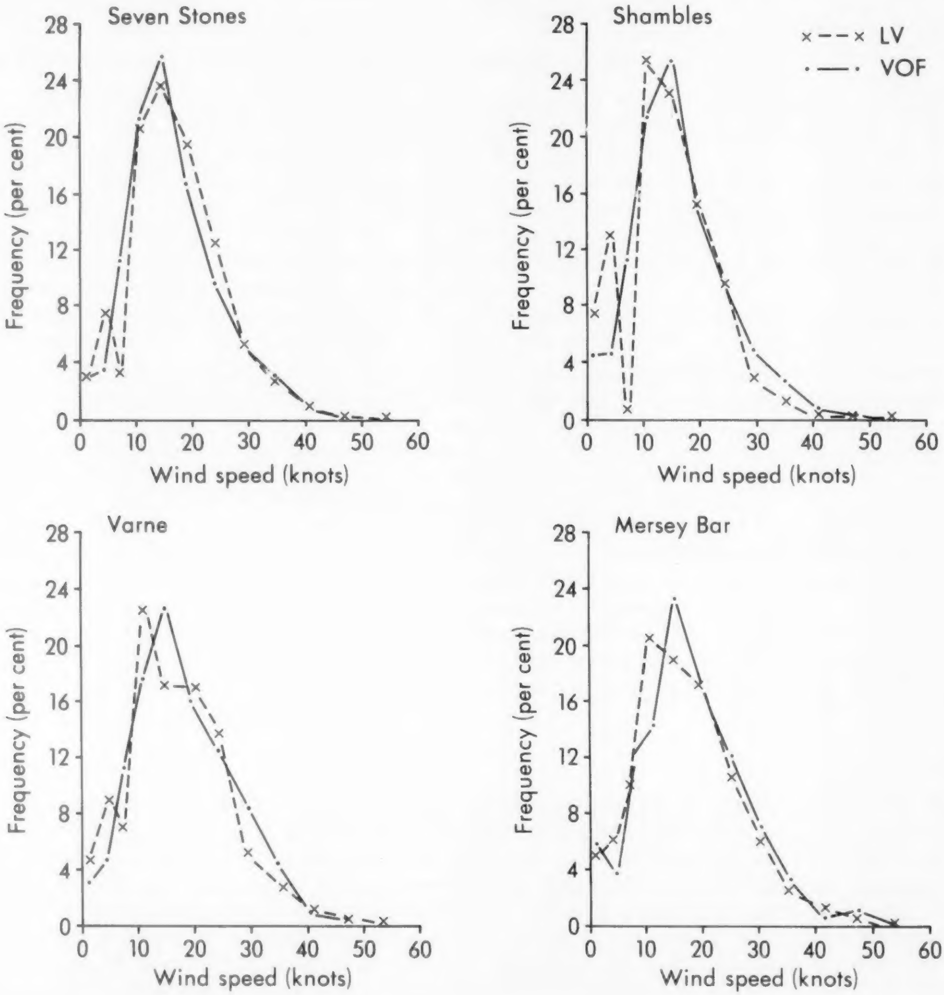

Figure 2(b) Wind-speed frequency distributions for light-vessels compared with those for co-located VOF ships.

Unfortunately, this process reduced the number of observations from the data sets and only four stations were considered to have enough data for comparison purposes.

For initial comparison the measured wind speeds were grouped according to the scientific Beaufort scale and the means and standard deviations of those estimated winds corresponding to the measured groups were calculated. The results are shown in Fig. 3 for OWS 'I' and 'J' and LV Seven Stones and Varne. The mid-point of each Beaufort force class for the measured data is plotted against the mean of the estimates with one standard deviation of the estimated wind speeds shown.

The data fit a straight line fairly well but there is a large scatter in the estimated data. The visual observations appear to be underestimated but this effect could well be due to the different averaging

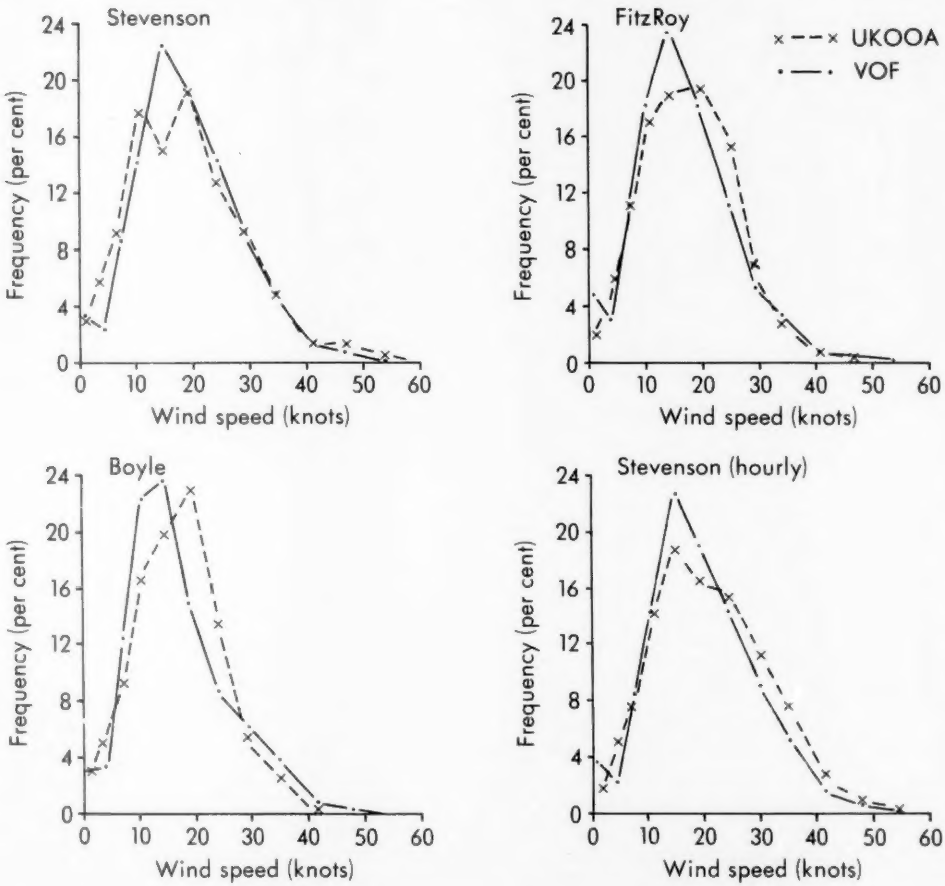

Figure 2(c). Wind-speed frequency distributions for UKOOA ships compared with those for co-located VOF ships.

times used for each type of instrumental observation. The use of very short averaging times, as on the OWS (10–15 seconds), is likely to cause the observer to bias the estimation of the average wind speed towards the higher speeds registered by gusts. In such small samples of data produced here by the selection of simultaneous data this bias is likely to dominate the results. Over a long period of time and with a large number of observations the mean wind speed should be independent of the averaging time (except where this is very short) although the scatter about the mean will be greater for the short averaging times.

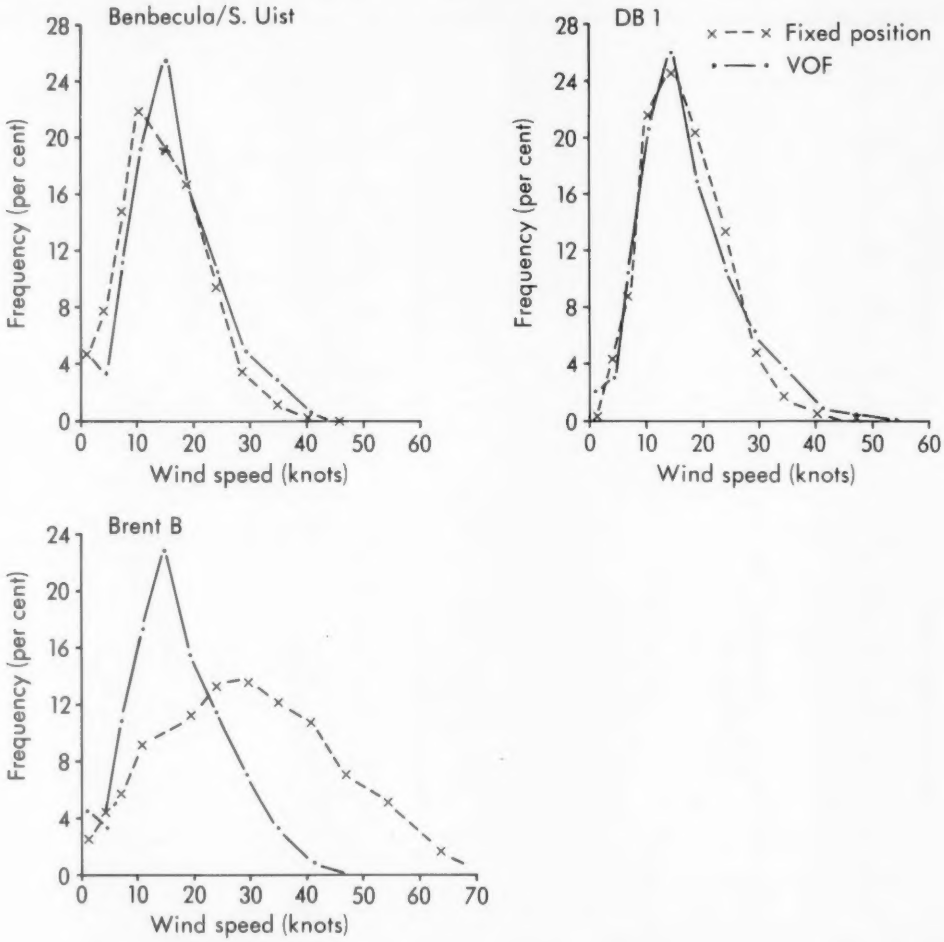

Figure 2(d). Wind-speed frequency distributions for South Uist (Benbecula), Brent and DB 1 compared with those for co-located VOF ships.

The calibration of the estimated wind speeds from the comparison described above simply produces a single correction for each Beaufort force. The scientific Beaufort scale was developed to produce such a correction and although some doubt has been expressed about its accuracy it is still generally held to be good (Kaufeld 1981).

An alternative method could be to correct each estimated speed individually. This would produce calibrated wind speeds equivalent to those of a different averaging time and the calibration would vary according to the type of instrumental data used. Such an attempt at calibration was made for OWS 'I' and 'J' from measured wind speeds and the corresponding estimates.

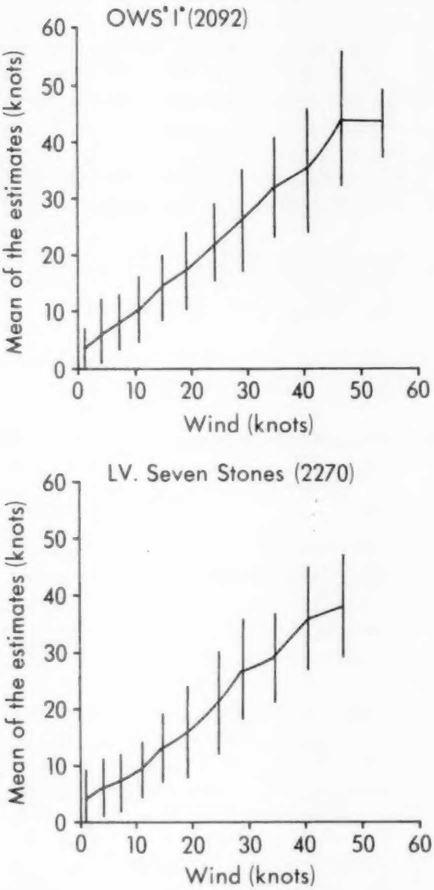

Figure 3. Mean of estimated data and standard deviation plotted against measured data using contemporaneous information. (Numbers of observations used are indicated.)

For each value of wind speed V ($V = 1,2,3\ldots$ knots) a calibrated speed was derived by taking the mean of all measured winds corresponding to estimates of V. The resulting wind speed distributions were rather distorted. It is likely that this was due to the method of estimation of wind speeds in Beaufort forces; this produces clusters of wind speed estimates around a mid-point value for each force.

In all the following analyses the complete data sets were used, not simultaneous data. This was because the process of producing data sets of simultaneous data takes only a sample of the original data. The VOF data is already only a small sample of the possible population of observations in the area and this sample should be compared with the best estimate of the whole population that is available.

The measured distributions are the best estimates available for the whole population even when the data set covers only a relatively short period. For those sites where the measured data cover approximately the same period as the estimated data sets, and the data are considered climatologically reliable, the comparisons should produce reliable results. It must be remembered, however, that the measured distributions are still only samples of the whole population and, though they are much better estimates of the whole population than are the VOF samples, they are still subject to possible sampling errors.

(b) *The effect of normalization of the VOF data*

There is a high density of observations during the summer of each year, possibly because there are more ships at sea during the summer than the winter. Consequently, there may be biasing of the VOF data towards the less severe summer conditions.

An attempt was made to reduce any such bias by defining a mean monthly observation count. The effect of setting such a count was that each observation for a month with M observations (where $M>30$) was reduced by a factor of $30/M$. Months with $M<30$ were not adjusted, all observations being used without the scaling.

This normalization, or weighting, of the data should reduce the effect of the larger number of observations available in the summer months without altering the distribution of wind speeds observed during those months.

Although this weighting action did produce some differences in the distributions it was very slight in all cases and could not be said to be significant.

(c) *Extreme-value analysis*

The estimation of extreme value is important for design and planning purposes. It is, therefore, of interest to compare the extremes derived from both the measured and estimated wind speeds.

Extreme values are estimated by fitting a distribution to the available data and extrapolating the tail of the distribution to the value having a cumulative probability of exceedance corresponding to the return period required. This gives the value expected to be exceeded, on average, once in N years, where N is the return period.

There are many distributions that can be used to predict extreme values. Several require the identification of annual maxima. This means that a long period (several years) of regularly observed data is necessary. Since the VOF data are randomly distributed in space and time such methods cannot be used because the maxima cannot be identified. The method used here to predict extremes from both measured and estimated data is to fit a 3-parameter Weibull distribution to the data.

The form of the distribution function (Weibull 1951) is

$$1 - P(V) = \exp\left\{-\left(\frac{V - V_o}{B}\right)^A\right\}$$

where $1 - P(V)$ is the probability of exceedance and A, B and V_o are the three parameters to be determined. This expression can be rearranged to give a straight line of the form

$$\ln[-\ln\{1 - P(V)\}] = A\ln(V - V_o) - A\ln B.$$

The data were fitted by computer program to this straight line by finding the best correlation between $\ln[-\ln\{1 - P(V)\}]$ and $\ln(V - V_o)$ for various values of V_o. The other two parameters, A and B, were given by the line of best fit with the optimum value of V_o The once in N-year value was then estimated by assuming that the number of observations that could be expected in N years was n. The corresponding probability of exceedance was $1/n$ and could be used in the expression

$$V_N = \exp\left(\frac{\ln\{-\ln(1/n)\} + A\ln B}{A}\right) + V_o$$

where V_N is the once in N-year extreme.

Because of the various averaging times (see Table II) it was necessary to convert the extreme values deduced for each station to extreme values appropriate to averaging times of one hour. This conversion, necessary for comparison purposes, was effected by means of figures derived by the Meteorological Office and given in Table III. Similar figures can be found in the Department of Energy Offshore Installation Guidance Notes (1977).

Table II. *Effective averaging times for the various sources of data*

3 seconds	15 seconds	1 minute	10 minutes	1 hour
Brent B	OWS	LV	UKOOA	VOF
			DB 1	Stevenson
			Benbecula	

Table III. *1 in 50-year extreme winds at 10 m and 100 m above sea level for various averaging times expressed as ratios of the 1 in 50-year hourly 10 m wind*

Height	Averaging time				
metres	10 minutes	1 minute	15 seconds	5 seconds	3 seconds
10	1.05	1.17	1.27	1.34	1.37
100	1.39	1.54	1.56	1.61	1.63

6. Results

The results of the extreme-value analysis are shown in Table IV for the 50-year return period. Both normalized and unnormalized VOF data were used. The normalized distributions tended to produce higher extremes, but for five stations there was no difference. Of the other ten stations, seven were increased by 1 kn, two by 2 kn and one, Varne, decreased by 2 kn because of normalization and an abnormal frequency distribution; the only wind of Beaufort force 11 occurred in a month of more than 30 observations so that its contribution to the normalized distribution was insignificant in the extreme-value analysis.

The large difference between extremes derived from the instrumental data from Brent B and the corresponding VOF data may be due to the height of the anemometer on the rig (108 m) and, also, to variations in observing practice. The extreme has been corrected to an equivalent hourly mean wind speed at 10 m but the original data were uncorrected.

Table IV. *Comparisons of 1 in 50-year extreme winds derived from measured and estimated data*

Station	50-year extreme wind speeds derived from: Measured data	Estimated data: Not normalized	Estimated data: Normalized	Differences between extremes derived using measured and estimated data: Not normalized	Normalized
			knots		
OWS 'I'	65	66	67	-1	-2
OWS 'J'	65	61	62	+4	+3
OWS 'L'	67	64	65	+3	+2
OWS 'M'	59	53	54	+6	+5
Seven Stones LV	66	58	59	+8	+7
Shambles LV	66	61	62	+5	+4
Varne LV	64	61	59	+3	+5
Mersey Bar LV	69	66	66	+3	+3
Stevenson (10 minute)	84	62	62	+18	+18
FitzRoy	57	59	60	-2	-3
Boyle	56	59	59	-3	-3
Stevenson (hourly)	69	62	62	+7	+7
DB 1	55	62	62	-7	-7
Brent B	78	62	64	+16	+14
South Uist	58	59	61	-1	-3

The very high extreme wind speed of the Stevenson 10-minute data may be due to sampling errors. There were only 23% of the possible total number of observations in the data set and three values above 60 kn contributed a comparatively large percentage to the distribution.

The differences between the extremes for 50 years from instrumental and estimated data are also shown. In 11 cases out of 15, the differences at the 50-year return period between extremes derived from instrumental data and from the estimated data were either reduced or remained the same when the estimated data were normalized.

Considering climatological reliability, as discussed above, and the number of observations in each sample it can be concluded that reliable data samples exist for OWS 'I', 'J', 'L' and the Stevenson hourly data. OWS 'M' is not included because of the low number of VOF estimates. This conclusion does not mean that the samples of data considered reliable are necessarily true representations of the climate in that area, only that it seems reasonable to assume so. It is quite possible that the data samples from other stations are good representations of the conditions despite reservations about their climatological reliability.

The difference between the 50-year return period extremes derived from the measured data and the normalized distribution of VOF estimates from the area surrounding the 'reliable' stations OWS 'I', 'J', 'L' and Stevenson (hourly) are respectively, −2, +3, +2 and +7 kn (Table IV). If it is borne in mind that the extremes are derived from wind speeds in Beaufort force classes (average range 5 kn) the extremes can only be considered accurate to within ±5 kn at best, and more likely ±7 kn, since the range of the Beaufort force classes increases with increasing wind speed. Consequently, the estimates of the 50-year extremes derived from each source are quite close. In fact only two stations have differences of more than ±7 kn, so that most of the 50-year extremes estimated from the VOF distributions are correct within the range of accuracy of the extremes derived from the measured distribution. Of the remaining five, three are stations with short periods of measured data, FitzRoy, Boyle and DB 1. One, South Uist, has measured observations from a land station (Benbecula) which would be expected to underestimate

the wind speeds compared with open sea values. The remaining station is OWS 'I' with an overestimation from the VOF distribution of 2 kn. There is no obvious explanation for this difference though it is most likely due to the sampling in one of the data sets concerned. For the OWS 'I' measured data, annual maximum wind speeds were extracted and fitted to the Gumbel (or Fisher–Tippett Type I) distribution to give estimates of extreme values. Extreme wind speeds were also estimated in this way for OWS 'J'. Since 'I' and 'J' are in similar climatic locations it should be possible to determine whether, or not, the results from OWS 'I' are reasonable by comparing the extremes from each OWS derived using each method of extreme value estimation.

Table V shows some of the resulting extremes from both methods of analysis and Fig. 4 shows plots of extreme wind speed against the return period. The estimated extremes from the Gumbel analysis are similar for both OWS 'I' and 'J' as are those estimated using the Weibull distribution. It would seem that the results for OWS 'I' can be considered reasonable and that it is the VOF distribution of estimated wind speeds which is unrepresentative of the climatic conditions in the area. The extreme values for the 50-year return period for OWS 'I' and 'J' wind speeds here are very similar. This is a coincidence and it should not be assumed that similar results are given for the 50-year return period for every location. There is no very obvious anomaly in the VOF distribution, but there is a small percentage of observations of wind speeds greater than 60 kn (0.04%). These observations are not necessarily incorrect but have not been matched by lower observations in the rest of the distribution. Therefore, the whole distribution becomes unrepresentative owing to a quirk of sampling.

The two stations with very large differences between estimated 50-year extremes can be discounted for reasons explained above. Most of the sites have underestimates of the 50-year extreme derived from the

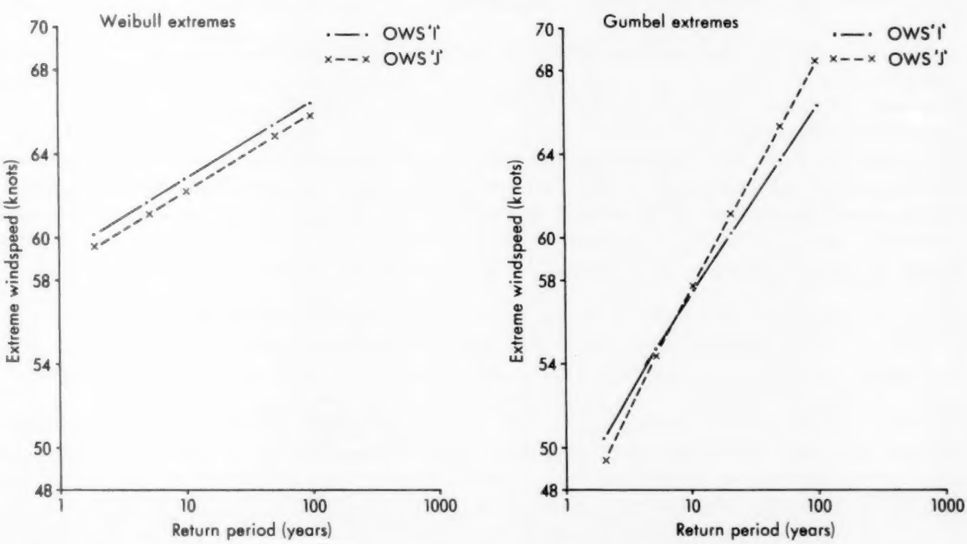

Figure 4. Extreme values of wind speeds for OWS 'I' and OWS 'J' derived from Weibull and Gumbel distributions.

VOF distribution compared with the corresponding extremes from the measured distribution. The average value of this underestimation is 5 kn. It does not seem unreasonable to assume that, in most cases, if 5 kn is added to the extremes estimated from the VOF distribution the resulting extreme value will be a better estimate. Obviously this will not be always true and, although sensible assumptions can be made regarding the apparent reliability of the data samples, there is no rule which will say whether or not any sample is a good representation of the conditions in the area over which it is taken.

If one considers the average differences between the extremes derived from the VOF estimates and the measured observations a similar conclusion can be drawn for extremes for the other return periods. That is, the average difference for the stations is about 5 kn, so a 5kn addition to the VOF estimate in general would improve the estimated extreme. It must be emphasized that this correction is an average result and will not necessarily improve the result in every individual case.

Table V. *Extreme wind speeds for OWS 'I' and 'J' derived using Weibull and Gumbel (or Fisher-Tippett Type I) distributions*

Return period	OWS 'I' Weibull extremes	OWS 'I' Gumbel extremes	OWS 'J' Weibull extremes	OWS 'J' Gumbel extremes
years		*knots*		
10	63	57	62	58
50	65	64	64	65
100	66	66	66	68

7. Conclusions

The distributions of estimated wind speed observations are different from those derived from wind speeds taken from instrumental sources. These differences are most likely due to the different observing techniques used.

This study suggests that a distribution should not be considered reliable simply because it has been taken from instrumental sources. It may not be any better than a distribution of estimated observations. The quality of measurements must be taken into account and the length of time over which the data set exists is also important.

It seems that where there is no absolutely reliable set of instrumental data the VOF data in that area can be used with confidence and it is likely that if an addition of one Beaufort class is made to the 50-year return period extreme (and similarly to all other return period extremes) the result will be somewhat improved.

8. Acknowledgements

This work is part of a wave climate synthesis project carried out in collaboration with the National Maritime Institute with the support of the Maritime Technology Committee.

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Appendix

Table IA. *Comparison between the limits of wind speed for the Beaufort scale numbers with those for the 'scientific' Beaufort scale*

Beaufort scale Equivalent speed at 10 m above ground Limit	Force	'Scientific' Beaufort scale Equivalent speeds at 20 m above sea surface Limit
knots		*knots*
<1	0	0–2
1–3	1	3–5
4–6	2	6–8
7–10	3	9–12
11–16	4	13–16
17–21	5	17–21
22–27	6	22–26
28–33	7	27–31
34–40	8	32–37
41–47	9	38–43
48–55	10	44–50
56–63	11	51–57
$\geqslant 64$	12	$\geqslant 58$

50 years ago

The following extract is taken from the *Meteorological Magazine*, December 1932, **67**, 249.

The British Polar Expedition to Fort Rae

During the first International Polar Year in 1882-3 a combined British and Canadian expedition under Captain Dawson occupied Fort Rae on the shore of the Great Slave Lake in 63°N. In spite of its comparatively low latitude, this station was of great importance, especially for observations of terrestrial magnetism and aurora, because it lies very near the zone of maximum frequency of aurora which surrounds the magnetic pole. When the second International Polar Year was planned for 1932-3, one of the important aims was the determination of the change of the magnetic elements during the interval of fifty years, and for this purpose it was necessary to occupy as many as possible of the earlier stations. The re-occupation of Fort Rae fell to the British share, while other stations in the extensive sub-polar regions of North America were the objectives of Canada and the United States.

The British Expedition consists of a party of six, Mr. J. M. Stagg* (leader), Mr. W. R. Morgans, Mr. P. A. Sheppard, Mr. A. Stephenson, Mr. W. A. Grinsted and Mr. J. L. Kennedy. Although the Polar Year did not officially start until August 1st, the party left England in May in order to have as long a time as possible for the construction of special huts, the erection of the instruments and generally to get the station into working order. They reached the settlement on June 19th, at the beginning of the short northern summer, accompanied by about 600 cases of instruments and food, all of which had been specially packed because of the cost and difficulty of transport. Mr. Stagg writes: "Our recollection of

* Later Director of Services, Meteorological Office.

the bustle of the early days at Rae is full of packing cases, curious Indian onlookers and swarms of hard-sucking mosquitoes, which, taking advantage of our occupation along other lines, had ample opportunity to feast on the fresh English blood they seem to relish so much.

"The first big jobs were the preparing of huts for instrumental gear. By earlier arrangements with the Hudson Bay Company and the Royal Canadian Mounted Police, of which there is a detachment here, we were spared the trouble of erecting dwelling-house and sleeping quarters. But other disused Indian shacks had to be converted and reconditioned. One, to house the photographically recording magnetic instruments, was made non-magnetic, light-proof and heat-insulated by building a double-walled chamber with wood-wool from our packing cases in the interspace and then fitted with a double door and piled up with turf and muskeg outside. Another old log hut was dismantled and transplanted from one end of the settlement to the other for manufacturing hydrogen in and filling our pilot and meteorograph balloons, while a third to house the engine generator and storage battery for the continuous lighting of the photographic recording instruments was largely reconditioned. A special completely non-magnetic hut for the absolute magnetic observations was built. Fortunately we found, ready made, a substantial log hut we could use for the main meteorological observatory and office.

"By the beginning of July many of the meteorological instruments were erected and observations begun, but it was nearer the beginning of August before the magnetograph chamber was satisfactorily complete and all the three independent sets of magnetic recorders properly settled down. By August 1st every instrument was functioning, and the complete routine of observations every three hours throughout the day was instituted. Already, in July, aurora had been noticed on every evening. Rae must be near, if not actually inside, the zone of maximum auroral frequency.

"From our early days here, the Indians have been amused spectators of our activities. The balloons we send off daily specially interest them. They feel sure that the unusually long rainless period we had in August had some connexion with the ultimate purpose and fate of the balloons in the high atmosphere, and attribute to us a specialised form of super medicine-man technique. A thunderstorm with lightning flash to ground near the settlement, nearer than they cared to recollect they had ever seen one before, confirmed them in this belief."

The new station is not actually on the site of that of 1882-3, but some 20 miles further up the lake in one of the largest Indian settlements in northern Canada. The old site was overgrown by bush, but the little island on which Captain Dawson erected his anemometer is still known by the natives as "White Man's Island." The old station has not been entirely abandoned, however, as the programme includes parallel magnetic observations at the old and new Forts to determine the secular change in the magnetic elements since the first Polar Year. Mr. Stagg adds: "We are taking advantage of the visits there to use the station as the other end of a base-line connecting the two Forts for simultaneous photography of aurora for height determinations."

Obituary

We regret to record the death on 30 May 1982 of Mr R. Hill, Higher Scientific Officer, who was stationed at Nottingham Weather Centre. Russell Hill joined the Office in 1946 as a Scientific Assistant and worked at a number of forecasting outstations including Bawtry, Finningley, London/Heathrow Airport and Shawbury. He was promoted to Higher Scientific Officer while at Shawbury in 1971, and the following year was posted to the office at Royal Air Force Watnall (which later became Nottingham Weather Centre).

Mr Hill had a dry sense of humour; he was a keen gardener and enjoyed foreign travel.

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NOTICES

It is requested that all books for review and comunications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ and marked 'For Meteorological Magazine'.

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